

Mind The Gap

The Productivity-Augmented Phillips Curve: Foundations and
Results

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Preface

This thesis marks the end of my studies. I wish to thank my family – for vast amounts of moral and financial support throughout my years of study, Professor Ragnar Nymoen at the University of Oslo – for encouragement and constructive feedback, and finally, Inga Longvastøl Flem – for making it all worthwhile.

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Abstract

In this thesis, I examine the behavior of inflation and unemployment in the United States, the United Kingdom and Norway, and test to what extent we can explain inflation and unemployment dynamics using models that allow real wage growth to diverge from labor productivity growth.

Chapter 1 presents the characteristics of the “New Economy” period. A simple Phillips curve model is included for illustrative purposes. Possible explanations for the macroeconomic behavior of the U.S. are pointed out, and some historical data on labor productivity growth rates is presented.

In Chapter 2, the price-wage spiral, an important part of price-wage dynamics, is presented and explained.

In Chapter 3, the core model of this thesis – the productivity-augmented Phillips curve – is derived. Wage aspirations are explained and incorporated into the wage setting process. The neoclassical factor rewardance results are demonstrated, and placed in connection with the productivity-augmented Phillips curve, ultimately relating these results to inflation. A section on the natural rate of unemployment is included, and the connection between the NAIRU and the productivity-augmented Phillips curve is discussed. I also look at the effects of productivity growth on the Phillips relationship, and further, how productivity might affect the price-wage spiral. Finally, the more general Phillips relation of the ‘Triangle’ model is discussed.

Chapter 4 is the main investigative part of my thesis. I estimate several Phillips curve type models using Ordinary Least Squares regression, examining the relevance of the productivity-augmented Phillips curve. Data for the U.S., U.K. and Norway is analyzed. Evidence is found suggesting that the gap between labor productivity growth and wage aspirations growth (which affects actual wage growth) has a negative and statistically significant effect on the change in inflation rates over time. The explanatory power of this gap is found to be stronger for the U.S. and the U.K. than for Norway. I also compare some of my main findings for the U.S. to those in Ball and Moffitt (2001).

Chapter 5 concludes.

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1 The U.S. 1996-2000: A New Economy?

The term “New Economy” refers to the development of certain macroeconomic variables in the U.S. during the second half of the 1990s. Unexpected¹ behavior in especially three variables led journalists, politicians and economists to believe that the U.S. economy had gone through a structural shift; those three variables were the inflation rate, the unemployment rate and the rate of productivity growth.

Authors such as Alan Blinder referred to the performance of the U.S. economy as “generally superior” (Blinder, 2000). The title of J. Bradford DeLong’s “What Went Right in the 1990s? Sources of American and Prospects for World Economic Growth” paper demonstrates a similar view – the U.S. economy had improved its performance. Additional potential explanations for this “New Economy” are discussed in Ball and Mankiw (2002), such as greater openness to international trade and improved job market matching and the acceleration of productivity growth. As for the acceleration of productivity growth, they state that this aspect was a central feature of the New Economy. Popular media wrote about a “trauma theory” (as presented by Alan Greenspan), where ‘traumatized workers’, in fear of losing their jobs, did not push for higher wages.² Certainly, such a phenomenon can be related to greater openness of trade and the advent of large-scale outsourcing of jobs. Whatever the reasons for the sense of job insecurity among workers (there may be several), the point is that wage demands were not growing much. Given the high labor productivity growth of this period, the story goes, this essentially led to wage growth lagging productivity growth. These developments did not go un-linked with another central feature of the “New Economy” – low inflation rates. For, if profits were rising and wages not, wouldn’t that put downward pressure on pricing decisions throughout the economy?

The story is as follows: the unemployment rate which was thought to give non-

¹As opposed to what we would expect when examining an economy with a well-behaved NAIRU environment.

²For instance, The New York Times printed an article called “Job Insecurity of Workers Is a Big Factor in Fed Policy” in 1997.

accelerating inflation (the NAIRU) was estimated to be somewhere in the neighborhood of 6 percent for the United States (see Ball and Mankiw, 2002). What happened after 1995, was that the unemployment rate fell far below this level *without* a significant change in the inflation rate. In fact, inflation remained low (compared to historical inflation rates since fiat money was introduced) throughout the whole period referred to as “The New Economy”. This clearly signifies a break with what the standard Phillips curve relationship predicts; movements in either inflation or the unemployment rate should give a movement in the opposite direction for the other variable (i.e. should unemployment be pushed below what is considered normal for the economy, one would expect a rise in the inflation rate).³ Over 1996-2000 both these variables reached low levels and remained relatively low throughout the period. This fact is the apparent paradox of “The New Economy”.⁴

Table 1: Average U.S. inflation (π) and unemployment rates (U)

Period	Average inflation	Average unemployment
1981 - 1985	5,5%	8,3%
1986 - 1990	4%	6%
1991 - 1995	3%	6,6%
1996 - 2000	2,5%	4,6%
2001 - 2005	2,6%	5,4%

Unemployment and inflation data from the U.S. Bureau of Labor
Statistics (<http://www.bls.gov>)

³See Stiglitz (1997): page 5.

⁴Paradox because it breaks with standard theory. Blinder (2000) refers to the unexpectedly high productivity growth rate over this period. However, this is not a paradox, as we have no established theory of what rates of productivity growth can or should be expected. The standard theory of NAIRU is well-established and has a solid theoretical foundation (see Ball and Mankiw, 2002); that for a given inflation rate, lower unemployment will lead to higher bargaining power on behalf of workers and thus higher wage growth. This will, for given profits, induce firms to increase their prices, so a higher rate of inflation results.

The period of the “New Economy” – circa 1996-2000, was a period with impressive macroeconomic performance. It has the lowest average inflation rate (2,5%) and the lowest rate of unemployment (4,6%) of these five-year periods. What is perhaps most striking, is that average unemployment for the period as a whole is approximately 2 percentage points below the consensus NAIRU estimate – while the average inflation rate of this period is lower than in the period preceding it (which had an unemployment rate average of 6,4 %). Thus, unemployment fell far below the NAIRU estimate without triggering an accelerating inflation rate – average inflation was actually lower during the “New Economy” period (as compared to previous periods). To explain this, either the NAIRU must have somehow rapidly decreased (through the arrival of a truly new economy), or this period must have been one with very beneficial supply shocks. The latter is given support in the somewhat agnostic conclusion of Blinder (2000), where all being admitted is that productivity growth was high for a longer period than earlier thought possible. Thus, no views of changed fundamentals are invoked; it is simply stated that the total growth in labor productivity over the period 1996-2000 was higher than expected or thought likely.

The standard formulation of the tradeoff between unemployment and inflation can be represented by an expectations-augmented Phillips curve of the type:

$$\Pi = \Pi^e - a(U - U^*) \quad (1)$$

where Π is inflation and Π^e is expected inflation. U^* is the NAIRU, and U is the actual unemployment rate. Thus, the constant a measures the effect on inflation when unemployment deviates from the natural rate of unemployment (by natural we also understand NAIRU - the non-accelerating inflation rate of unemployment).⁵ For instance, if U is below the natural rate, $(U - U^*)$ is negative. This negative number is then multiplied by a (which has a negative sign), such that Π must increase. This is the standard result

⁵The two terms will be used interchangeably throughout this thesis.

– as unemployment drops below the natural rate, inflation will start increasing.⁶ If we assume $\Pi^e = \Pi_{t-1}$, solve for the inflation difference ($\Delta\Pi = \Pi_t - \Pi_{t-1}$, i.e. the change from one period to the next), and add a supply shock v , the Phillips curve becomes

$$\Delta\Pi = -a(U - U^*) + v \quad (2)$$

According to Ball and Mankiw (2002), the distinction between U^* and v can be considered somewhat arbitrary – this because they both shift the inflation-unemployment tradeoff. That is, they are not necessarily distinguishable when it comes to their *effect* on inflation and unemployment. However, for the sake of thorough and precise analysis, it would be wise to give this some additional thought; whereas the NAIRU is usually assumed to be determined by the fundamental structure of the economy, such as labor market functioning, tax structure and demographics – variables that typically cannot be changed rapidly or too often, supply shocks are often of a more short-lived and erratic character. If this is correct, one would perhaps expect significant, structural changes in the economic environment to have a permanent effect on the NAIRU, while supply shocks can be expected to have more short-lived effects. The question of whether supply shocks really shift the NAIRU should also be raised – after all, a shock and the effect it has - is expected to disappear. In Ball and Moffitt (2001) supply shocks are considered changes in the inflation-unemployment tradeoff for a *given* NAIRU.

Combinations of inflation and unemployment previously thought incompatible emerged and persisted during the era of the “New Economy”. Clearly, this challenged orthodox opinion. What is important to notice, is that a supply shock may trigger episodes like the one that took place in the latter part of the 90’s in the U.S.: inspecting (2), we observe that even if unemployment is below the natural rate U^* for a while, giving rise to higher inflation *ceteris paribus*, a supply shock that has the effect of giving lower inflation *ceteris paribus*, can ensure that Π actually *decreases* even while $U < U^*$. Of

⁶For a discussion of the term natural rate of unemployment, see Ball and Moffitt (2002) and Stiglitz (1997).

course, when the supply shocks eventually disappears, one would expect inflation to start increasing rapidly. The bottom line is: if the economy is hit by strong and persistent supply shocks, it might (for a while) seem like important structures of the economy are subject to new rules or no rules at all. Obviously, when examining the period of the “New Economy”, one should take both the possibility of fundamental, structural change and that of persistent supply shocks seriously.

The second aspect of “The New Economy” that seems widely agreed upon, is the high growth rate of productivity – more precisely, labor productivity growth. The boost in productivity growth rates was often linked to new, evolving and more frequently used technologies such as computers and the Internet. DeLong (2000) makes the point that rapidly decreasing prices of components used in information technology settings, such as semiconductors (used in CPUs) and computers, may have contributed to accelerating use of information technology equipment. If such technologies are subject to increasing returns to scale, this may have had a positive effect on the productivity of many workers, and possibly a substantial effect on the economy as a whole.

Table 2: Average U.S. labor productivity growth rates (θ)

Period	Labor productivity growth rates
1976 - 1980	0,96%
1981 - 1985	1,66%
1986 - 1990	1,26%
1992 - 1995	1,14%
1996 - 2000	2,16%
2001 - 2005	2,36%

Source: OECD Stat.Extracts

(<http://stats.oecd.org/Index.aspx?DataSetCode=PDYGTH>)

From table (2) we see that the “New Economy” period is a period with a high average labor productivity growth. The average growth rate for the 20 years preceding this period was 1,25%. Thus, average yearly productivity growth during our New Economy

period was nearly twice that of the period 1976-2005. Also, one should note that the macroeconomic performance of the 5-year period after “The New Economy” was very strong. Average yearly inflation was only slightly above that of our new economy, and unemployment somewhat higher – though it did not reach the NAIRU estimate of approximately 6,2% (the peak unemployment rate for this period was at 6,0% in 2003). Labor productivity increased more during 2001-2005 than 1996-2000.

The development of inflation, unemployment and productivity growth in the U.S. from 1996 to 2001 was remarkable. Surely, commentators’ decision to nickname this period can be understood. While unemployment is usually linked to inflation via NAIRU theory and Phillips curve relations (assumed to hold at least in the short run), no such link is usually posed between inflation/unemployment and productivity. The standard Phillips does not include productivity growth, as it relies on the neoclassical foundation that productivity growth directly feeds into the wages of workers. What one should be aware of, is that if the relationship between productivity growth and wage growth is somehow disturbed, this can alter the Phillips relation – i.e. the link between inflation and unemployment. This should be kept explicitly in mind when investigating periods like “The New Economy”.

2 The Price-Wage Spiral

The workings behind the idea of a ‘price-wage spiral’ is conveniently summed up by Blanchard (2003): “Think about what happens when firms respond to an increase in demand by increasing production:

- Higher production leads to higher employment.
- Higher employment leads to lower unemployment.
- Lower unemployment leads to higher wages.
- Higher wages leads to increased production costs, leading firms to increase prices.
- Higher prices lead workers to ask for higher wages.

- And so on.”

Whether we start from an increase in the demand for goods, or an increase in the real wages of workers does not really matter (we would then be looking at a wage-price spiral, but the underlying mechanisms at work would be the same), as argued by Blanchard (1986). If we let increased real wages be the start of the process (that is, if we let nominal wages increase for a given level of price inflation), the spiral effects follow; and so, independent of which part of the economy the motion comes from, the spiral of changes in wages and prices follow. What this spiral of change represents are the actions taken by the two bargaining parts (workers/unions on one hand, firms on the other) in order to maintain and increase their “share of the pie”. Whereas workers or the unions that represent workers want as high real wages as possible, and as low unemployment as possible, firms want to maximize their profits. The pie is given by the value of the sales of the firm, i.e. its total income.

Through wage bargaining workers/unions and firms decide how much of the pie is allocated to workers (through money wages), and how much is allocated to firms (through profits). The price-wage spiral shows how price changes spread throughout the economy; an increase in the price of a good does not simply occur, leaving the system at rest. The price change induces workers to try to maintain their previous level of real income by asking for a higher money wage. If the demands of workers are met, surely this will affect the profit of firms, and so they might want to raise their prices in response to the higher real wages to maintain some level of profits. We see that there is an interdependent dynamic to this process, where the two actors (workers and firms) each respond in turn to the actions taken by the other part. This interdependent dynamic is the price-wage spiral.

3 The Productivity-Augmented Phillips Curve

In Ball and Moffitt (2001) a special version of the Phillips curve is presented, where productivity growth plays a potential role in shifting the Phillips curve⁷ This is done by combining a wage-setting relation and a price-setting relation in which the aspirations for wage growth affect actual wage setting. The wage setters (which in this model are the workers themselves) are assumed to have a target for real wage growth that depends negatively on the unemployment rate (U), positively on growth in labor productivity (θ) and “wage aspirations” (A). The negative relationship between U and target wage growth is the standard one in Phillips curve models, where high unemployment weakens the bargaining power of workers, so that they typically will obtain lower wage increases under high unemployment compared to situations with low unemployment.

3.1 Wage aspirations

Aspirations for wage development A are formed according to:

$$A_t = \beta \cdot A_{t-1} + (1 - \beta) \cdot (\omega_{t-1} - \pi_{t-1}) \quad (3)$$

Aspirations are determined by previous wage increases (represented by ω), given an initial A (the aspiration in the period where the economy is assumed to start). The size of β determines how fast aspirations are updated after changes in real wage growth. We see that as $\beta \rightarrow 1$, aspirations for wage increase in the present period (t) will only depend on the aspirations of the previous period ($t-1$). Thus, β gives us the speed of aspiration adjustment when actual real wage growth changes. If $\beta = 1$, aspirations will remain stationary, and aspirations will be the same forever. As $\beta \rightarrow 0$, a marginal weight is put

⁷The phrase ‘productivity-augmented Phillips curve’ was used in Gruber (2003). In so-called “main course” theories of wage determination, productivity (along with foreign prices) are elements of a ‘wage corridor’ - a corridor that sets the upper and lower limits for wage growth. In the productivity-augmented Phillips curve, however, we examine a closed economy, so no foreign prices are included. While the foreign price element does not relate the Phillips curve and main-course models, the productivity element does – acting, in both models, as a determinant of the rate of wage growth that can be sustained in the long run.

on aspirations from previous periods, and workers will aspire for approximately the same real wage increase in the current period as in the previous.

Two crucial assumptions regarding wage aspirations are made in Ball and Moffitt (2001). The first one is that aspirations affect *actual* wage setting (i.e. aspirations are not just ideas without influence on economic decision-making. The link is made explicit by allowing workers to behave as wage setters). The second assumption is that aspirations are to some degree linked to the wage increases experienced in the past.

Keeping the “traumatized worker” in mind, one should give these aspirations some additional thought. Clearly, the approach taken by Ball and Moffitt (2001) is a rather simple one. A fundamental critique of such an approach to aspirations would be: if aspirations are thought to reflect some sense of “fair wages”, what happens to aspirations if the cost of fair wages is too high? If ‘too high’ wage increases leads to the loss of jobs (or, workers *think* ‘too high’ wage increases will lead to the loss of jobs), will they push for the wages they perceive as fair? If not, wage growth aspirations depend on more than past aspirations and past real wage growth.

3.2 Aspirations and the price of labor

In this section, I will demonstrate how aspirations for wages may affect the link between productivity and (real) wages. These wage aspirations have an impact on the actual real wage development. The crux of the Ball and Moffitt (2001) model is allowing for imperfect updating of wage aspirations, and it is this imperfect updating that allows wage growth to deviate from the growth of labor productivity. The idea of aspirations builds on habit formation in wage expectations, where workers can “get acquainted” with a certain rate of wage increases. If there is a positive shift in the growth of labor productivity, workers could - everything else given - get a higher real wage without reducing the profit of the firms. However, considering habit formation allows wages to fall out of line with labor productivity growth because workers are accustomed to a certain rate of wage growth. Wage development can therefore deviate from the development of productivity. This is a break with neoclassical analysis.

The neoclassical relationship between wages and productivity can be analyzed within a framework where a representative firm uses labor input in the process of producing the amount of output that maximizes profits. In the case with two inputs, capital and labor, the firm has to choose the combination of inputs that yield the highest amount of produce which it can sell at the prevailing prices (which the firm will take as a given). The problem of the firm is:

$$\max_{\{K_t, L_t\}} \Pi_t = p \cdot f(K_t, L_t) - r_t \cdot K_t - w_t \cdot L_t \quad (4)$$

Equation (4) represents the profit maximization problem of the firm, with K and L as the control variables of the firm. It takes the price p as exogenously given, and chooses the use of the two input factors, capital (K) and labor (L), where the prices of these inputs are r , which is the rental price of capital, and w , which is the wage rate paid to workers.

The solution to the problem is found by taking the first-order derivatives of the choice variables K and L , and setting them equal to zero:

$$\frac{\partial \Pi_t}{\partial K_t} = p \cdot (f'_K)_t - r_t = 0 \quad (5)$$

$$\frac{\partial \Pi_t}{\partial L_t} = p \cdot (f'_L)_t - w_t = 0 \quad (6)$$

$(f'_K)_t$ is the marginal product of capital at time t – that is, how much production increases when the capital stock is marginally increased given the production already obtained at time t . Similarly, $(f'_L)_t$ measures how much total production increases when a worker puts in an additional (marginal) effort (this might be an hour of overtime for an already employed worker, or the hiring of *one* extra worker, depending on how we define it.) We see that wages are always set according to their contribution to production. So, if a

worker works an hour extra, he earns the value of what he produces during that hour. Thus, the neoclassical framework yields the result that wages always increases at the same rate as labor productivity. We will never see labor productivity growth deviate from real wage growth in this type of framework, and since this holds for all points in time, the real wage will always equal a worker's value contribution to production, that is, the price of the output he produces multiplied by the amount of output he produces.

The link between factor productivity and factor payment obtained in the neoclassical framework rests on the assumption markets are perfectly competitive. This means that we implicitly assume that there are no unions disturbing labor supply and/or affecting wage setting, and that firms do not pay so-called efficiency wages. There is no need for effort-enhancing wages of this type, as workers, who are paid their full marginal product, have no incentive to be lax while working.

The model presented and estimated by Ball and Moffitt (2001) does not make any assumptions with regard to market structure. However, in their analysis lies an implicit assumption regarding wages, namely that wages need not follow labor productivity one-to-one in the short run. This is clearly at odds with the neoclassical result that $f_L = w$ at all points in time.

3.3 Wage and price inflation

The equation for target real wage growth is given by

$$(\omega_t - \pi_t^e)^{target} = \alpha - \gamma \cdot U_t + \delta \cdot \theta_t + (1 - \delta) \cdot A_t + \varepsilon_t \quad (7)$$

where ε_t is the error term. π_t^e is the inflation expected to take place from t-1 to t. A is the wage increase that workers aspire to achieve. From (7) we see that the weight attached to productivity growth in wage growth aspirations is δ , and the weight attached to aspirations is $(1 - \delta)$. The size of δ determines to what extent aspirations actually have an effect on the growth of real wages. If we let $\delta = 0$, (7) reduces to $(\omega_t - \pi_t^e)^{target} = \alpha - \gamma \cdot U_t + A_t + \varepsilon_t$, so that aspirations have an effect on the determination of wages, while productivity growth has no effect. The other extreme is where δ equals unity - so that the

aspiration A is multiplied by zero and disappears from the wage setting relation, leaving us with the relation $(\omega_t - \pi_t^e)^{target} = \alpha - \gamma \cdot U_t + \theta_t + \varepsilon_t$. This is the solution obtained under neoclassical assumptions, where aspirations are not a part of wage setting and productivity increases affect wages instantaneously.

The model allows both habit in wage increase expectations as well as actual productivity growth to affect wage setting. In this respect, it deviates from the standard neoclassical prediction, where the price of labor (i.e. wages) equals the marginal product of labor at *all* points in time. If aspirations for instance is lower than productivity growth for some time, wages will fall out of line with the marginal product of labor. While the Ball-Moffitt model allows these kind of deviations from neoclassical theory to take place and persist through the short run, they will be corrected for in the long run, where wages, aspirations and productivity all grow at the same rate.

The nominal wage growth for period t (ω_t) is set in period $t-1$, making wage setters guess inflation in period t for obtaining their target level of *real* wage growth. A certain way of expectations formation is assumed on behalf of wage setters: what is commonly referred to as adaptive or static expectations. Under such an assumption, agents use the inflation rate of one period to forecast the inflation of the next period ($\pi_{t+1}^e = \pi_t$, or $\pi_t = \pi_{t-1}$). Wage setters set the nominal wage increase to be equal the target real wage growth plus expected inflation: $\omega_t = (\omega - \pi)_t^{target} + \pi_t^e$. Solving for $\omega_t - \pi_t^e = (\omega - \pi)_t^{target}$, setting $\pi_t^e = \pi_{t-1}$, and solving for ω , we get:

$$\omega_t = \alpha + \pi_{t-1} - \gamma \cdot U_t + \delta \cdot \theta + (1 - \delta) \cdot A_t + \varepsilon \quad (8)$$

Equation (8) is a “wage Phillips curve” which links nominal wage inflation to the price inflation of last period (believed by wage setters to prevail into the current period), the unemployment rate U and a weighted sum of productivity growth θ and aspirations A .

The next step is determining the inflation process. Here, inflation is produced by firms when their costs increase (i.e. unit labor costs increase faster than labor productivity), plus an error term. Specifically, the “cost increase” is the wage growth rate less the

productivity growth rate from a period to the next. So, if wage growth lies above the productivity growth, the firms face a cost increase, and this will lead firms to raise their prices in perfect relation to this cost increase. Thus, any cost increase that firms experience (and are not compensated through by productivity growth) will lead to a price increase of the exact same order. Inflation is thus given by:

$$\pi_t = \omega_t - \theta_t + \nu_t \quad (9)$$

where ν_t is the error term. To obtain the productivity-augmented Phillips Curve (PAPC), which is the one to be estimated, equation (8) is combined with equation (9) to get the *price* Phillips curve, which determines the rate the general price level in the economy will increase at. As our wage Phillips curve takes both productivity growth and wage growth aspirations into account (and these factors affect price inflation), we get a richer model of inflation determination. For instance, it can allow inflation to remain low while the employment rate is high; if productivity increases faster than real wages, unit labor costs drop. It then becomes relatively cheaper to hire labor, and so unemployment might drop if firms decide to act on this incentive to use more labor input in their production processes. This is crucial to our analysis of the “New Economy”.

To obtain the *price* Phillips curve, which is the empirical Phillips curve Ball and Moffitt estimate and compare to a standard Phillips curve, we insert for ω from (8) in (9) and get: $\pi_t = \omega_t - \theta_t + \nu_t = \alpha - \gamma \cdot U + \delta \cdot \theta + (1 - \delta) \cdot A - \theta + \nu + \varepsilon$. Rearranging leads us to our price Phillips curve:

$$\pi_t = \alpha + \pi_{t-1} - \gamma \cdot U_t + (1 - \delta)(\theta - A_t) + \epsilon_t, \quad \epsilon_t = \varepsilon_t + \nu_t \quad (10)$$

One should note that the price Phillips curve can be written on an error correction form. Simply move the π_{t-1} term left of the equality sign and notice that $\pi_t - \pi_{t-1} = \Delta\pi$. This interpretation of the equation states that the year-to-year change in the inflation rate is a function of the unemployment rate and the relative sizes of θ and A . Again,

the unemployment rate U , which is multiplied by the (positive) parameter γ , has a negative impact on the change in inflation rate. If $\Delta\pi$ equals some positive number, and unemployment increases, price inflation will be lower in the next period. This is because as unemployment increases, workers claim more modest wage increases. We know from the price inflation relation (9) that since wage inflation will be lower, price inflation will also be lower (for a given θ). So, as unemployment increases in period t , the change in price inflation from period t to $t+1$ will be lower than from period $t-1$ to t , all else being equal.

3.4 The NAIRU

If one wishes to invoke the idea of a non-accelerating inflation rate of unemployment – that is, the unemployment rate which gives an inflation rate that is constant (i.e. it does not accelerate or decelerate over time), the following can prove illustrating: let labor productivity grow in line with aspirations such that $\theta = A$. In the long run there are no shocks (or, rather, the negative shocks and positive shocks cancel each other, so ϵ equals 0). The NAIRU unemployment gives non-accelerating inflation, that is, $\Delta\pi = 0$. The price Phillips given by (10) curve now becomes: $0 = \alpha - \gamma \cdot U$. We solve for the non-accelerating inflation rate of unemployment and get: $\gamma \cdot U = \alpha \iff U^{NAIRU} = \frac{\alpha}{\gamma}$. Thus, the NAIRU in the PAPC is defined as the U that gives $\Delta\pi = 0$ and $\theta - A = 0$. Movements in $(\theta - A)$ are considered to be supply shocks, as they affect the cost of labor. Any movement in either θ or A (given that they do not move in opposite directions but with the same magnitude) will affect the unit labor cost. Since these costs are the main component of price decisions made in firms, it seems fair to treat them as supply shocks. Such movements are thought to alter the unemployment/inflation tradeoff implicit in the Phillips curve for a given NAIRU, not alter the NAIRU itself. Even though not explicitly mentioned in Ball and Moffitt (2001), the NAIRU is thought to be determined by more fundamental structures than the short-run divergence of θ and A . Since it is assumed that these variables grow at the same rate in equilibrium, such that $(\theta - A) = 0$, they do not affect the NAIRU. Rather, they can temporarily change the (π, U) menu for a given

NAIRU. In the long run, however, we return to the same natural rate of unemployment. This, however, is not a logical implication that is reached regardless of how one views the NAIRU concept. Rather, with the given formulation of aspirations, real wage growth always catches up with productivity growth as we approach the long run, and thus, equilibrium unemployment will be the same as before any growth divergence between θ and A occurred.

The story of the model is therefore: if the growth of θ and the growth of A fall out of line for some time, this can give rise to unexpected combinations of inflation and unemployment. Though these combinations of (π, U) may be experienced in the short to medium run, they will not prevail in the long run. As workers update their aspirations after recent increases in real wage *growth*, they will eventually aspire to have real wages grow in line with marginal labor productivity – aspirations grow at the same rate as productivity. As price inflation becomes stationary (because when $(\theta - A)$ is zero, firms do not systematically change prices), so does wage growth, and the unemployment rate that prevails is the NAIRU. One should also keep in mind that the speed towards long-run equilibrium (or stationarity) depends on how fast aspirations are adjusted, i.e. the size of the parameter β .

The difference between (10) and an ordinary Phillips curve is the inclusion of the $(\theta - A)$ term. This term represents a potential break with the neoclassical assumption that factors of production at all times are rewarded according to their marginal contribution – if the term differs from zero, wages will not move in tandem with productivity (as suggested by the neoclassical framework). They will be equal in the long run, as aspirations update towards actual productivity growth and employment rates change, but this might take a long while. If we start from a situation of $\theta = A$, as these are growth rates, a deviation implies an acceleration or deceleration of one or both. Thus, inflation will be stationary even though both aspirations and productivity grow (as long as they grow at equal speed). There will be upward pressure on inflation when aspirations for wage growth grow faster than productivity, and downward pressure when productivity grows faster than aspirations. Thus, starting from a steady state, an acceleration or a

deceleration in (at least) one of these growth rates is needed for the inflation rate to change.

Apart from the unemployment rate, this model allows productivity growth changes to affect inflation. If we look at the equation for price inflation, and rewrite it in terms of wage inflation, we see that wage growth is given by productivity less price growth (ignoring the error term). Since we will generally assume that $\beta < 1$, updating of wages will not be immediate as productivity growth changes. Aspirations, as specified by (3), cannot change unless productivity growth does. The sequence of events is that first productivity growth changes, leading to changed wage growth. This wage growth then feeds into the wage growth aspirations of workers. So, the main idea behind this extended Phillips curve is to let productivity growth changes affect the profitability of firms and thereby their decisions with respect to the use of labor input. Persistence of the effects of productivity growth changes are ensured by a sluggish adjustment of wage aspirations, such that the profitability of firms and potentially the unemployment rate will be affected for some time if $\theta \neq A$. The existence of slowly adjusting aspirations allow changes in the rate of labor productivity to affect inflation through changes in unit labor cost.

3.5 Productivity growth

Phillips curve models – whether they allow productivity growth to have effects on inflation and unemployment or not – do not seek to *explain* productivity growth. In a given period, the productivity growth that will prevail during a certain interval t , θ_t , is not explained by the model. The productivity growth simply arrives. No assumptions regarding the development of productivity growth are made. We allow productivity growth to vary substantially from year to year and decade to decade.

In the real world, one might be able to explain some of these trends in productivity growth by tracing them back to actual historical events that are likely to affect the productivity of workers. One example of such an effort was made in “What Went Right in the 1990s? Sources of American and Prospects for World Economic Growth” (De-Long (2000)), where the point is made that rapidly evolving information technology, and

especially the use of computers, may have contributed to the observed boost in labor productivity growth in the second half of the 90s in the United States. Such historical investigations are, though interesting and important enough, not the focus of this thesis. Rather than asking “why productivity growth?”, I ask what the *effects* of changes in labor productivity growth is on central macroeconomic variables. Especially is the effect on the tradeoff between inflation and unemployment emphasized.

3.6 Productivity growth and the ‘Price-Wage Spiral’

A central question is if the inclusion of the productivity growth and aspirations growth gap ($\theta - A$) in any way affects the price-wage spiral. In answering this, one should start with an analysis of why these spirals occur. This was covered in section (2). The lesson was that for a *given* surplus (i.e. a given level of profits for the firm), any changes in wages or prices affect what firms and workers get in *real* terms. As the two parties negotiate on how to share the surplus, they push wages or prices in their favored direction when given the opportunity. For instance, workers (wanting higher real wages), push up the nominal wage in period $t - 1$. Firms lose profits unless they raise their prices, so in period t they adjust their prices upward, and inflation increases. This is the spiral.

We then turn to the question of what might weaken/strengthen this spiral, or even prevent it from taking place. In the productivity-augmented Phillips curve framework, the new elements are productivity growth and aspirations of wage growth. Aspirations are not the prime mover of anything; aspirations move over time only as the result of other changes in our present framework (nothing happens to A unless real wage growth changes, which requires a change in inflation or nominal wage growth). Thus, one should look at productivity growth. Assume we are initially in steady state, and then aggregate demand increases at time $t+1$, such that $AD_{t+1} > AD_t$. Allowing for an additional change in the economic environment we let labor productivity increase more rapidly (a positive shift in the growth rate), such that $\theta_{t+1} > \theta_t$.

With higher labor productivity for given wages, firms will increase their profits. With higher profits, firms can either raise real wages or hire more workers - or a combination

of the two. If the surplus generated by the boost in productivity growth is large enough, the following scenario might take place; the first year, when $(\theta - A)$ is at its largest, the firm will hire quite a few new workers. Some aspiration updating in the next period will lead to real wage increases, but they are not yet as high as the increases in productivity. Additional hiring takes place, and there might be room for some more real wage growth. If the initial differences between θ and A are large enough, such that the economic surplus generated by the productivity growth acceleration is of some size, we might get a scenario where both real wages and unemployment increase without spurring accelerating inflation. Why? Because firms have no need to pass on the costs of increased real wages, as they make more profits.

We see that if the productivity growth acceleration is large enough, and aspirations for wage growth fall short of this growth, the increased surplus of the firm makes it able to hire many workers (leading to a low unemployment rate) at the *same* time as workers get real wage increased. So, allowing $(\theta - A) > 0$ gives room for higher employment and increased wage growth without firms having to resort to price increases. A possible outcome of our initial scenario ($AD_t \uparrow, \theta_t \uparrow$) is a weakening of the price-wage spiral, and potentially a full prevention of its occurrence.

3.7 The 'Triangle' Model of Inflation

An additional perspective on the inflation process is presented in the so-called 'Triangle' model of inflation (see Gordon, 1997). There, Gordon points to a revision of the basic Phillips curve consisting of two steps; one being the introduction of a zero long-run tradeoff between inflation and unemployment, the other: including supply shocks.⁸ This resulted in a Phillips curve with three variables explaining the inflation process; inertia, supply shocks, and aggregate demand.

Intertial inflation is the part of the inflation that is inherent in the economic system, regardless of the status of aggregate demand and supply. It is thought to be slow-moving, such that in steady state (with no excess demand and no supply shocks) inflation will

⁸See page 302 of the Brookings Institute Paper No. 2 (1998).

change little from year to year. This being a fairly stable process, expected inflation in period $t + 1$ would be close to that of period t .

It should be clear that supply shocks may have an impact on the rate at which the general price level increases. If, for instance, the price of oil started to increase rapidly, this could potentially affect pricing decisions throughout the economy. As firms using oil or oil related inputs experience soaring costs of these inputs (and seek compensation through charging higher prices for their final products), workers on their hand will ask for wage increases as a compensation for their weakened purchasing power – the 'price-wage spiral' immediately comes to mind. The link between supply shocks and inflation seems obvious.

The third variable contributing to the determination of inflation is aggregate demand, or, rather, the level of aggregate demand relative to potential output. We are in a situation with 'excess' demand if aggregate demand is higher than potential output – however, it is not obvious how to actually represent excess demand. Different proxies can be used – for instance, one could employ the difference between the natural rate of unemployment and actual unemployment.⁹ As unemployment moves below the natural unemployment rate (or NAIRU), aggregate demand will start increasing. This will result in increasing inflation, and is a very fundamental result in Phillips curve type models. The triangle thus consists of inertial inflation, supply shocks and a measure of excess demand.¹⁰

The zero long-run tradeoff is now a fairly standard assumption in macroeconomics. This tradeoff emerges due to the fact that unemployment gravitates towards the natural rate of unemployment in the long run. As this process cannot be put out of play, an attempt to keep unemployment below the NAIRU in the long run (through expansionary monetary policy) will only result in price increases (and, these price will be occurring at

⁹This rests on the assumption of a link between unemployment and demand. Such a link is provided in Blanchard (2003): page 129 .

¹⁰One could of course have excess demand with a negative sign in front. This corresponds to aggregate demand lagging potential output, and is a situation where unemployment is above the natural rate. The inflation rate will then be decreasing.

a faster rate the longer we have $U > U^{NAIRU}$). Hence, there is no long-run tradeoff. (In the short to medium run, however, monetary policy can push unemployment away from U^{NAIRU} , but then at the cost of accelerating inflation. As we reach the long run, only the cost remains.)

In Gordon (1997), inertial inflation is represented by the lagged value of inflation. Using just one lag of inflation to represent inertia, the 'Triangle' model of inflation can be written as

$$\pi_t = a \cdot \pi_{t-1} + b \cdot D_t + c \cdot s_t + \varepsilon_t, \quad (11)$$

where D_t measures excess demand (D equal to zero means that aggregate demand equals potential output). s_t is our supply shock (s_t means no supply shocks that affect the rate of inflation take place during time interval t), and ε_t is the error term. Though this is a very simple representation of a triangle model, it demonstrates the main point; inflation history, demand conditions and supply shocks are the main determinants of inflation. We notice that this formulation of the Phillips relationship explicitly takes cost-push and demand-pull factors into consideration (through s_t and D_t , respectively). Gordon (1997) states that "the role of the lagged inflation terms is to capture the dynamics of inertia, whether related to expectations formation, contracts, delivery lags or anything else." That is, if we let inertia be captured by inflationary expectations, and we assume those expectations to be static or backward-looking (as Gordon indeed does), a link between the 'Triangle' model and the standard expectations-augmented Phillips curve presents itself.

If one makes the assumption that Ball and Moffitt (2001) do, and let workers operate under static expectations, the two models (Ball-Moffitt and 'Triangle') coincide with respect to interial inflation – inflation today is dependent on inflation in the previous year (in the exact same manner), though a more general representation of the 'Triangle' might include more than one lag of inflation (i.e. π_{t-2} , π_{t-3} and so on). The price Phillips curve derived by Ball and Moffitt (equation (10)) includes the gap of productivity growth and real wage growth aspirations ($\theta - A$). As noted, this gap is essentially a supply shock, so

the models have in common that they allow supply shocks to affect the rate of inflation. Unemployment is, however, treated differently in the two models. While the unemployment *rate* itself is a variable in the price Phillips curve of Ball and Moffitt, the Triangle model uses the *gap* between actual and natural unemployment (as a proxy for excess demand).

Both models (Ball-Moffitt and Triangle) allow for inflation inertia (for instance due to expectations). As for the treatment of the supply, the productivity-augmented Phillips curve only includes one specific supply shock (the gap between labor productivity growth and wage growth aspirations), while the Triangle model has a more general supply shock variable. This should come as no wonder, as the productivity-augmented Phillips curve was created to investigate to what extent inflation behavior in “The New Economy” could be explained by including this special type of supply shock (productivity growth) and slowly moving wage aspirations. Even though unemployment is treated somewhat differently in these Phillips curve equations, the mechanisms at work are basically the same; the higher the level of employment, the larger the chance of the economy experiencing inflationary pressures (*ceteris paribus*).

The Ball-Moffitt model should thus be considered a special case of the Triangle model of inflation (which in turn can be considered an extended Phillips curve relation), designed to allow divergence of wage and productivity growth rates, and to empirically investigate the effect of such divergence on inflation.

4 Estimation

4.1 Data and measurement

All data used in this chapter are collected from the OECD Statistics webpage.¹¹ Unemployment is the unemployment rate for all persons as reported by OECD. Inflation is measured as the percentage change in the CPI (consumer price index), all items included. Nominal wage growth refers to the growth rate of labour compensation in the business

¹¹Contact m.solem.johansen@gmail.com if you are interested in the datasets used in this thesis.

sector excluding agriculture.

However, not all variables needed for the estimation of a productivity-augmented Phillips curve are observable. In Ball and Moffitt (2001), two of the variables used for estimating the productivity-augmented Phillips curve are constructed; these variables are the growth rate of labor productivity and aspirations for real wage growth.

My approach to modelling aspirations follows that of Ball and Moffitt, while that of labor productivity growth does not. Ball and Moffitt measure productivity growth as the change in the log of output per hour in the business sector (excluding agriculture) after taking cyclical effort movement into account. The reason for taking effort into account is as follows: when demand starts increasing (at the start of an economic expansion), firms will not start hiring new workers immediately. Rather, one would expect that in the first phase of the business cycle, workers will simply increase their effort in order to meet the increased demand. If the upswing persists, businesses will start hiring more workers. This means that one should take this effort effect into account when measuring productivity growth; for, if this effect exists and is of a significant size, measured productivity growth will be biased positively. Some of the increase in production will be due to movement in effort rather than due to higher actual productivity. In order to cope with this, Ball and Moffitt (2001) regress measured productivity growth on the change in the logarithm of hours worked. They find, however, that adjusting for cyclical adjustment explains only a small fraction of productivity growth. For the reason of simplicity, I abstain from performing a cyclical adjustment to labor productivity growth, and use the series as reported by the OECD. My reason for doing so is that, despite this lack of cyclical adjustment, these data capture the broad patterns (as discussed in Ball and Moffitt, 2001: pages 11-12) of productivity growth rates over time (see table (2)). It is reported in Ball and Moffitt (2001) that their empirical results are not very sensitive to the use of productivity growth series (adjusted versus non-adjusted).¹²

The inclusion of wage growth *aspirations* is one of the key elements in our new Phillips curve; these aspirations affect real wages, and real wage growth affects the profits of firms

¹²See Ball and Moffitt, 2001: page 12, footnote 3.

over time. We believe that pricing decisions to some extent rely on profits (as discussed in section (3.6)), where I explain how the price-wage spiral can be weakened by firms making higher profits. We thus have a potential link between aspirations and inflation. Wage growth aspirations are given by $A_t = \beta \cdot A_{t-1} + (1 - \beta) \cdot (\omega_{t-1} - \pi_{t-1})$. While real wage growth $(\omega - \pi)$ can be observed and measured, β and A cannot be observed. In choosing β , the parameter which determines the speed of adjustment of aspirations to developments in real wage growth, I follow the main approach by Ball and Moffitt, and set β equal to 0.95.¹³ Low values of β seem unrealistic, as this generates 'much' change in aspirations when real wage growth changes. If wage growth is relatively high one year, a high β would imply that workers 'get accustomed' to this high wage growth, and expect this for the future. If the period following this were to be one with low real wage growth, workers would suddenly aspire for low wage growth. As aspirations are meant to capture some sense of 'fair wage increases', a less rapidly moving β seems realistic. What is perceived as fair does not change radically from year to year. On the other hand, a 'too' large β implies that workers do not really consider the evolution of real wages in the near past, but rather, base their aspirations on wage increases in the distant past. If this was true, workers would not be adapting their wage growth aspirations, and "workers still want the wage increases they received in the 1950s" (see Ball and Moffitt (2001): page 15).

Also, in order to derive this aspirations variable, one needs a suitable initial A . I follow Ball and Moffitt, and let aspirations in the initial period be equal to the trend real wage growth in that period, as calculated by the Hodrick-Prescott filter.¹⁴ In the case of the United Kingdom my data starts in 1972, so this is the initial period in this economy. The HP-filtered trend growth in real wages for 1972 is equal to 3.3 percent. Assuming that aspirations and the actual trend in real wages were not too different in this period, aspirations for real wage growth were 3.3 percent in the U.K. in 1972. Thus,

¹³This value for β is also used in Gruber (2003).

¹⁴This filter decomposes a time series into a trend component and a cyclical component. I follow Ball and Moffitt (2001) in setting the 'punishment' parameter λ equal to 1000. The HP-filter performs a minimization problem of the form: $\min \sum_{t=1}^T (y_t - \tau_t)^2 + \lambda \sum_{t=2}^{T-1} [(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})]^2$.

$A_{1972} = A_0 = 3.3$. Next, we need to determine aspirations for 1973. This is done by inserting the values for A_{1972} , β and actual real wage growth in 1972. Using $A_{1972} = 3.3$, $\beta = 0.95$ and $(\omega - \pi)_{1972} = 5.99$, we get $A_{1973} = 0.95 \cdot 3.3 + (1 - 0.95) \cdot 5.99 = 3.44$. We get the result that in 1973, workers in the U.K. aspired to have a 3.44 percent real wage increase. The procedure is repeated for all periods in my dataset, giving us values for the aspirations variable for the period 1973-2008.

Once we have found the wage aspirations variables, we can construct the gap between labor productivity growth and real wage growth aspirations. This is the central modification of the empirical Phillips relation; it allows us to see if the inclusion of this gap variable increases the ability of the model to explain changes in inflation. As discussed in sections (3.1) through (3.6), this gap – which affects the profitability of firms – if large and persistent enough, can contribute to keeping inflation low despite low levels of unemployment (be it the unemployment rate or the level relative to some natural rate).

4.2 Empirical investigation

Along the lines of Ball and Moffitt (2001), I ask whether the inclusion of the productivity growth less wage growth aspirations gap $(\theta - A) - \text{PA}$ gap from now on – can improve the performance of the Phillips curve, and, if so, to what extent. The estimation strategy adopted is the standard one of Ordinary Least Squares (OLS). We make the following assumptions regarding the error term ε_t :

$$(A1) \quad E(\varepsilon_t) = 0$$

$$(A2) \quad \text{Cov}(U_t, \varepsilon_t) = 0$$

$$(A3) \quad \text{Cov}(\varepsilon_t, \varepsilon_{t+j} | U_t, U_{t+j}) = 0 \text{ for } j \neq 0$$

$$(A4) \quad \text{Var}(\varepsilon_t | U_t) = \sigma^2$$

where E is the expectations operator. (A1) states that the error term on average should equal zero. Cov is the covariance between the unemployment rate U and the error term ε , so (A2) means zero covariance between our explanatory variable and the error term. (A3) holds that the error terms should be independent. (A4) is a requirement of constant

variance of the error term.

Assuming these assumptions to be met, we can estimate the standard Phillips curve using OLS. The standard (expectations-augmented) Phillips curve estimated is

$$\Delta\pi_t = \beta_0 + \beta_1 \cdot U_t + \varepsilon_t, \quad (12)$$

This equation investigates to what extent the unemployment rate can explain the change in the inflation rate from period to period. β_0 is the intercept term. From theory, as discussed thoroughly throughout this thesis, we expect the unemployment rate to affect the rate of change in inflation. This effect is in turn expected to be negative – that is, when running regressions, we expect β_1 to be negative. The productivity-augmented Phillips curve to be estimated is the same as (12) with the addition of the PA gap ($\theta - A$):

$$\Delta\pi_t = \beta_0 + \beta_1 \cdot U_t + \beta_2 \cdot (\theta - A) + \varepsilon_t, \quad (13)$$

where we expect the coefficient on the PA gap, β_2 , to be negative (as discussed). A few regressions will also be performed on a non-expectations-augmented Phillips curve, where the inflation *rate* (and not the rate of change in the inflation rate) is the left-hand side variable. Including the PA gap, we estimate

$$\pi_t = \beta_0 + \beta_1 \cdot U_t + \beta_2 \cdot (\theta - A) + \varepsilon_t, \quad (14)$$

or, without the PA gap:

$$\pi_t = \beta_0 + \beta_1 \cdot U_t + \varepsilon_t \quad (15)$$

4.3 Testing the assumptions

If assumptions (A1) through (A4) hold, we can estimate equations (12), (13), (14) and (15) to obtain coefficient estimates that are unbiased and consistent.¹⁵ I therefore conduct

¹⁵Unbiased means that the expected value of the estimator equals the true value of the estimator ($E(\hat{\beta}_1) = \beta_1$ and $E(\hat{\beta}_2) = \beta_2$, and so on). Consistent means that the probability limits of our estimators approach their true values as the sample size tends to infinity.

three tests to see if my data is characterized by these properties. First, I test if the residuals found in my regressions are approximately normally distributed (i.e. test for normality). If they are, (A1) holds and we can use standard tests (e.g. F-tests and t-tests). Then, I investigate if the error terms have heteroskedastic properties. If they do, the variance of the error term will not be constant, and assumption (A4) breaks down. Lastly, I will look into the issue of autocorrelation. If autocorrelation is found (and found to be statistically significant), assumption (A3) breaks down, the error terms no longer being independent.

Table 3: Assumption test results

Country	EE	$\chi^2_{normality}$	$F_{heteroskedasticity}$	$F_{autocorrelation}$
US	(13)	0.15692 [0.9245]	2.2351 [0.0897]	5.3182 [0.0101]
US_{corr}	(16)	2.4537 [0.2932]	0.54329 [0.8108]	2.9764 [0.0673]
UK	(13)	5.81185 [0.0545]	1.0431 [0.4027]	0.78186 [0.4664]
Norway	(13)	3.1324 [0.2088]	1.2203 [0.3245]	1.8044 [0.1814]

EE is the model specification used for testing the assumptions.

In table (3) test results for normality, heteroskedasticity and autocorrelation are given. In the case of the U.S., the chi square value clearly indicates normality (i.e. the hypothesis that our data is characterized by normality cannot be rejected at the 5% level). The null hypothesis of homoskedastic error terms cannot be rejected, so (A4) holds. However, the F-value for autocorrelation (5.3182) exceeds the critical level at the 5% level, indicating autocorrelation. This calls for corrective measure before running regressions on U.S. data.

The U.K.: none of the null hypotheses are rejected at the 5% level, indicating that are assumption of normality, absence of autocorrelation and absence of heteroskedasticity are valid. We thus proceed with OLS.

Also in the case of Norway will OLS also give consistent and unbiased estimators, as none of the null hypotheses are rejected. Normality, absence of autocorrelation and

heteroskedasticity seem to be characteristics of Norwegian data as well.

4.3.1 Dealing with autocorrelation

When autocorrelation is present – as it is in U.S. data – the estimators found are no longer the best linear unbiased estimators. In addition, inference is no longer valid, forcing us to take some kind of corrective measure.

I follow Ball and Moffitt (2001) in dealing with autocorrelation by including two lags of the inflation change variable in my regression.¹⁶ The new equation is

$$\Delta\pi_t = \beta_0 + \beta_1 \cdot \Delta\pi_{t-1} + \beta_2 \cdot \Delta\pi_{t-2} + \beta_3 \cdot U_t + \beta_4 \cdot (\theta - A) + \varepsilon_t, \quad (16)$$

We estimate equation (16), and run normality, heteroskedasticity and autocorrelation tests on the results. The results are summarized under US_{corr} (where corr means that it has been corrected for autocorrelation) in table (3). We see that extending the US Phillips curve with two lags of the change in inflation reduces the value of the autocorrelation coefficient to 2.98, which means we cannot, at a 5% significance level, reject the hypothesis that there is no autocorrelation (the critical value being 3.34). Normality still holds, and the data does not display heteroskedasticity. Thus, equation (16) can be used to obtain the best linear unbiased estimators for the U.S.

4.4 Results

I estimate equations (12), (13), (14), (15) and (16) using data from 1972-2008 (Norway and the U.S.) and 1973-2008 for the United Kingdom.

The expectations-augmented Phillips curve (non-productivity-augmented) performs fairly well on U.S. data from 1974-1995 (the “Old Economy”). The model is capable of explaining half of all variation in the inflation rate (see table (1)). Unemployment is significant and negative, as we expected, showing that during this period, more unemployment lead to a marked deceleration of inflation. As we extend the analysis to include

¹⁶See Ball and Moffitt (2001): page 24.

the New Economy period (1996-2000), the explanatory power of the model is weakened if we leave the two lags on $\Delta\pi$ out of the regression. R^2 drops from 0.52 to 0.35.¹⁷ This is the New Economy showing up in our results. However, including two lags of the inflation change gives the model increased explanatory power when we examine the New Economy period, as R^2 is 0.55 for this specification of the model. Estimating the productivity-augmented curve for the period 1972-2000 using an initial A of 0.49 increases the explanatory power of the model – R^2 increases from 0.55 to 0.69 when including the PA gap. The PA gap has the expected sign and is significant at the 5% level. Using a perhaps more realistic¹⁸ initial A , I obtain an R^2 of 0.74. Including the years through 2008 in our regression, we find that the explanatory power of the non-productivity-augmented (but still expectations-augmented) Phillips curve is at it's weakest, with an R^2 of 0.51 (equal to that of US1). As we try to explain the change in inflation rate over the whole period with the PA gap included, we get an R^2 of 0.66, which is lower than the R^2 of model US4. In all periods and specifications examined, the coefficient on the PA gap stays negative and of a magnitude of about -0.70, and it is statistically significant at the 5% level. My values for R^2 are very close to those found in Ball and Moffitt (2001) for the productivity-augmented Phillips curve. The intercept term and coefficient on the unemployment estimates are fairly stable (at about 3 to 4 for β_0 and -0.5 to -0.6 for β_3) and similar to those found in Ball and Moffitt (2001). Comparing models US2 to US4 and US5 to US6 we see that R^2 increases when the PA gap included, demonstrating the relevance of the PA gap. The predictive power gained by including this term seems to vary across time. This is in line with our intuition; as the gap is not constant, it matters more during some periods than others (and, it seems that it mattered quite a lot during

¹⁷Compare US7 and US8.

¹⁸Realistic because aspirations for a real-wage growth of about 0.5 percent seem quite low – especially if compared to Ball and Moffitts estimate of 4.2%. Ball and Moffitt advise us not to calculate aspirations based on periods of where aspirations and real wage growth diverge. They explicitly mention the period of the 70s as an example of this. I meet this criticism by computing an average value for the aspiration variable, which is the average of my estimate (which is probably biased downwards because of the above-mentioned reason) and the initial aspirations variable (A) found by Ball and Moffitt. This average (A_0^{AVG}) is then used when running regressions on U.S. data.

1974-2000).

Table 4: Phillips curve estimates for the U.S.

Model	EE	Period	PA Gap	β_0	β_3	β_4	A_0	R^2
US1	(12)	1974-1995	No	3.03 (1.091)	-0.50 (0.172)			0.51
US2	(12)	1974-2000	No	3.74 (1.381)	-0.59 (0.208)			0.56
US3	(16)	1974-2000	Yes	4.05 (1.172)	-0.53 (0.177)	-0.73 (0.228)	0.49	0.69
US4	(16)	1974-2000	Yes	4.16 (1.085)	-0.65 (0.163)	-0.75 (0.190)	AVG	0.74
US5	(12)	1974-2008	No	3.03 (1.091)	-0.50 (0.172)			0.52
US6	(16)	1974-2008	Yes	3.62 (0.935)	-0.57 (0.146)	-0.64 (0.174)	AVG	0.66
US7	(12)	1974-1995	No	8.85 (1.952)	-1.30 (0.278)			0.52
US8	(12)	1974-2000	No	5.24 (1.497)	-0.82 (0.225)			0.35

A_0 is the initial aspiration value.

US1-US6 are performed using specifications correcting for autocorrelation, i.e. they include lags of the change in inflation. However, I choose not to include the coefficients on these variables in this table (that is, I exclude β_1 and β_2), as they are not essential parts of my analysis, but rather variables included for the purpose of eliminating autocorrelation. For estimated coefficients on the lagged changes in inflation, see table (7) in the appendix.

Standard deviations are given in parentheses.

AVG refers to the average of my own A_0 calculation and the one used in Ball and Moffitt (2001), i.e. $\frac{(4.2+0.49)}{2} = \frac{4.69}{2} = 2.345 = A_0^{AVG}$.

US8 is estimated without lagged inflation change variables, and shows the weak explanatory power of the standard model when we include the New Economy period. US7 is the standard model without lags excluding the New Economy period.

EE is the equation estimated in the respective models.

Regression results for the United Kingdom 1973-2008 are given in table (5). UK1 estimates (12). The amount of variation in $\Delta\pi$ that can be explained is found to be 0.14. The coefficient on the unemployment rate is -0.59, leaving us with the 'correct' sign, but the effect is not all that strong, and not statistically significant at the 5% level (though by a very small margin). Extending the regression to include what was the New U.S. Economy (1996-2000), we perform the same regression. The results are very similar,

indicating that no New Economy took place in the U.K. from 1996-2000. Making use of the Phillips curve *with* the PA gap, we obtain the following results: for the years 1973-2000, R^2 increases from 0.13 to 0.58. The PA gap has an estimated coefficient of -1.56 and is statistically significant at the 5% level. The expectations-augmented Phillips curve performs equally well if we include the years 2001-2008, suggesting that deviations of wage growth aspirations from labor productivity growth played a strong role in determining the evolution of inflation over this whole period. The non-productivity-augmented Phillips curve performs poorly compared to the one *with* a PA gap. For the U.K., the PA gap is potent as an explanatory factor of inflation changes over this period, whereas the unemployment rate is not.

Table 5: Phillips curve estimates for the U.K.

Model	EE	Period	PA Gap	β_0	β_1	β_2	A_0	R^2
UK1	(12)	1973-1995	No	4.66 (2.672)	-0.59 (0.312)			0.14
UK2	(12)	1973-2000	No	3.98 (2.234)	-0.53 (0.270)			0.13
UK3	(13)	1973-2000	Yes	1.17 (1.669)	-0.30 (0.190)	-1.56 (0.301)	3.3	0.58
UK4	(12)	1973-2008	No	3.27 (1.625)	-0.46 (0.210)			0.12
UK5	(13)	1973-2008	Yes	0.84 (1.230)	-0.26 (0.150)	-1.52 (0.260)	3.3	0.56

Standard deviations are given in parentheses.

Models with with PA gap included are productivity-augmented Phillips curves.

$A_0 = 3.3$ is the authors' calculation.

EE is the equation estimated in the respective models.

Table (6) shows the results for Norway 1972-2008. Models N1-N3 and N7-N8 use $\Delta\pi$ as the dependent variable, while N4-N6 and N9-N10 use π as the dependent variable. The reason for running regressions on the non-expectations-augmented Phillips curve is that few of the right-hand side variables are statistically significant at the 5% level in the expectations-augmented specifications of the model – with the exception of β_1 and β_2 in model specification N8. The general results from these regressions are: the unemployment rate seems to be able to explain quite a lot of the variation in the inflation rate, with the

coefficient on U negative and often well below minus 1 (implying a strong effect of U on π) and always significant for models N4-N6 and N9-10. The R^2 fluctuates from 0.49 to 0.62 (for N4). N7-N9 give negative values for the coefficient on the PA gap, but they are not always significant. Comparing (N5) to (N9), we see that the inclusion of the PA gap increases R^2 , while R^2 decreases when adding it for the whole period (compare N4 to N10). In N10 the PA gap even has the opposite sign of what is expected, but the effect is never significant. We note that generally, Norwegian data do not match very well with the expectations-augmented Phillips curve (which must be considered the standard one in the literature).

The productivity-augmented Phillips curve succeeds to a fair extent in accounting for variation in inflation rates. In the U.S. (as confirmed by Ball and Moffitt, 2001) and the U.K., the PA gap improves the explanatory power of the models estimated here. It's effects are generally significant and of some size (especially in the U.K. does the gap improve the performance of the model). Whether adding this gap to Norwegian Phillips curves is more unclear; in one specification it slightly improves the explained variation in π (see results for N5 and N9), in another a slight decrease in explained variation follows (see N4 and N10). The productivity-augmentation thus seems like a potent explanatory variable. However, for the case of Norway, this variable does not seem as relevant (it is only statistically significant at the 5% level in model (N8), and there the effect is weaker than than typically found for the U.S. and the U.K.). We also note the absence of a typical expectations-augmented Phillips relationship for Norway.

Table 6: Phillips curve estimates for Norway

Model	EE	Period	PA Gap	β_0	β_1	β_2	A_0	R^2
N1	(12)	1972-1995	No	0.96 (1.034)	-0.36 (0.290)			0.07
N2	(12)	1972-2000	No	1 (0.930))	-0.35 (0.260)			0.06
N3	(12)	1972-1995	No	1.03 (0.870)	-0.33 (0.230)			0.05
N4	(15)	1972-2008	No	12 (0.930)	-1.64 (0.260)			0.62
N5	(15)	1972-1995	No	11.82 (1.054)	-1.76 (0.297)			0.56
N6	(15)	1972-2000	No	11.3 (1.126)	-1.81 (0.312)			0.49
N7	(13)	1972-1995	Yes	-0.29 (1.248)	-0.08 (0.320)	-0.58 (0.350)	4.6	0.18
N8	(13)	1972-2008	Yes	0.07 (1.034)	-1.13 (0.265)	-0.56 (0.294)	4.6	0.12
N9	(14)	1972-1995	Yes	10.8 (1.024)	-1.36 (0.278)	-0.65 (0.294)	4.6	0.69
N10	(14)	1972-2008	Yes	11.8 (1.024)	-1.92 (0.343)	0.22 (0.280)	4.6	0.50

Standard deviations are given in parentheses.

Models with with PA gap included are productivity-augmented Phillips curves.

Initial A_0 used (4.6) is the authors' calculation.

Note that models 1-3 and 7-8 use $\Delta\pi$ as the dependent variable, while models 4-6 and 9-10 use the inflation *rate* π as dependent variable.

EE is the equation estimated in the respective models.

5 Conclusion

In this thesis, I have looked at the theoretical foundations for, and the actual historical developments of, important macroeconomic variables. Especially have I looked at inflation and unemployment, and the relationship between them. The standard approach to inflation and unemployment dynamics (the simple Phillips curve) has been discussed and compared to more general relationships. All theories discussed belong to the same class of models – they are models where inflation typically moves in the opposite direction of unemployment, due to the effects of lower unemployment on wage and price increases. These effects are then propagated by the price-wage spiral.

I have examined the theoretical foundations of the Phillips curve, and examined what the implications of altered assumptions in this model are. Special attention has been given the neoclassical factor rewardance result for labor and wages. A breakdown of this result is seen to alter the Phillips relation, because it affects the relation between price growth and wage growth. If wage growth does not follow labor productivity growth, firms will generally pass on less inflation to consumers, since they have relatively lower unit labor costs. This can dampen the price-wage spiral, and possibly prevent it from occurring at all. If one wishes to use such concepts as the NAIRU, one is advised to keep these theoretical foundations in mind.

The productivity-augmented Phillips curve takes the breakdown of neoclassical foundations explicitly into account, by allowing wage growth and labor productivity growth to diverge in the short run. This can potentially change the inflation-unemployment dynamics of an economy. I have examined the so-called “New Economy” in light of this, and it seems that such changes have had a significant effect on the development of unemployment and inflation. Of course, all of the events that occurred in the latter part of the 90s in the U.S. relied heavily on the high rate of labor productivity growth over this period. My approach to modelling wage growth is based on aspirations for “fair wage growth”, where workers take historical values of such aspirations and real wage growth into account.

Estimating productivity-augmented Phillips curves for the U.S., the U.K. and Norway, I find that the introduction of a gap variable representing divergence of aspirations for wage growth and productivity growth generally increases the explanatory power of these models. This variable does indeed help explain inflation variation in the U.S. when looking at the years of the New Economy (1996-2000). For the U.K., large gains in explanatory power follow the inclusion of this gap in the estimated models. For Norway, the importance of this gap in the inflation process seems moderate. This gap variable has, in almost all estimated models, the expected sign, and the effects of it are generally found to be statistically significant.

The lesson is: we must become more critical of the assumptions we build our analyses on – the fact that something is true for a certain period of time does not make it true in general. We must also extend our knowledge of how psychological factors contribute to decisions affecting pricing, hiring and production. Only then can we hope to solve the puzzles of inflation and unemployment.

6 References

- Ball, L. and N. Gregory Mankiw (2002): “The NAIRU in Theory and Practice”, *Journal of Economic Perspectives*, 16(4):115-136.
- Ball, L. and R. Moffitt (2001): “Productivity Growth And The Phillips Curve”, *Economics Working Paper Series 450*, Johns Hopkins University.
- Blinder, A. (2000): “The Internet and The New Economy”, *The Brookings Institution Policy Brief No. 60*:246-248.
- Blanchard, Olivier J. (1986): “The Wage Price Spiral”, *The Quarterly Journal of Economics*, 101(3):543-565
- Blanchard, Olivier J. (2003): *Macroeconomics* (third edition). Prentice Hall.
- Bureau of Labor Statistics (2009): “Consumer Price Index”, <ftp://ftp.bls.gov/pub/special.requests/cpi/cpia1.txt>, downloaded 09/09-2009.
- DeLong, J. Bradford (2000): “What Went Right In The 1990s? Sources of American and Prospects for World Economic Growth”, in David Gruen & Sona Shrestha (eds.), *The Australian Economy in the 1990s*. Reserve Bank of Australia.
- Gruber, Joseph W. (2003): “Productivity Growth and the Phillips Curve in Canada”, *International Finance Discussion Papers No. 787*.
- Gordon, Robert J. (1997): “The Time-Varying NAIRU and its Implications for Economic Policy”, *The Journal Economic Perspectives*. 11(1):11-32.
- OECD Stat.Extracts, <http://stats.oecd.org/Index.aspx>, downloaded 09/09-2009.
- Stiglitz, J. (1997): “Reflections on the Natural Rate Hypothesis”, *The Journal of Economic Perspectives*, 11(1):3-10.

Utichelle, L. (1997): “Job Insecurity of Workers Is a Big Factor in Fed Policy”,
<http://www.nytimes.com/1997/02/27/business/job-insecurity-of-workers-is-a-big-factor-in-fed-policy.html>, downloaded 14/11-2009.

7 appendix

Data definitions:

- Inflation rate (BLS): annual percentage change in the consumer price index. All urban consumers (CPI-U), U.S. city average, all items.
- Unemployment rate (BLS): unemployment rate (unadjusted), 16 years and over. BLS series number: LNU04000000.
- Inflation (OECD): consumer price index, percentage change from previous period.
- Labour productivity growth (OECD): labour productivity annual growth rate.
- Nominal wage growth (OECD): labour compensation per unit labour input, business sector excluding agriculture, annual growth rate.
- Unemployment rate (OECD): harmonised unemployment rate, all persons.

Table (1): BLS data.

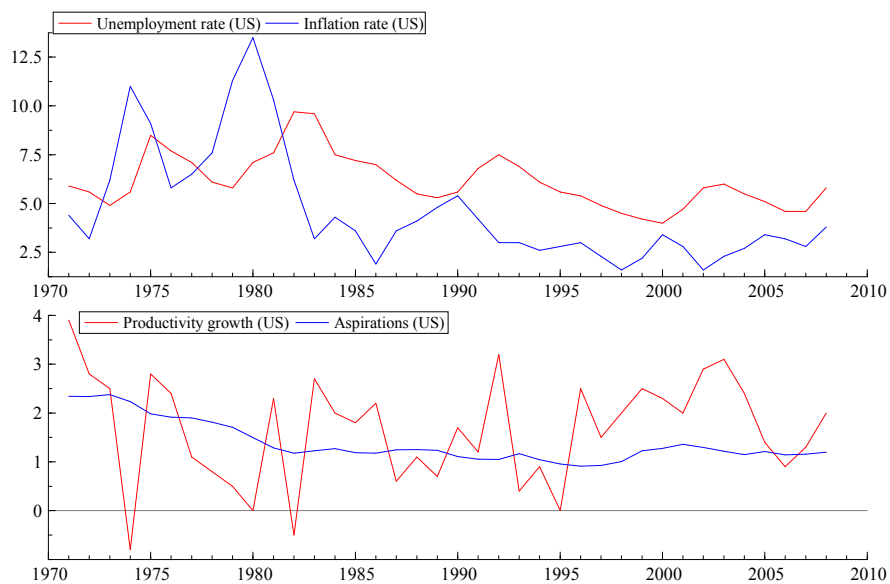
Tables (2)-(7): OECD data.

Table 7: Phillips curve estimates for the U.S. - all coefficients included

Model	β_0	β_1	β_2	β_3	β_4	R^2
US1	3.03 (1.091)	0.332 (0.132)	-0.46 (0.127)	-0.50 (0.172)		0.51
US2	3.74 (1.381)	0.336 (0.148)	-0.43 (0.144)	-0.59 (0.208)		0.55
US3	4.05 (1.172)	0.280 (0.126)	-0.38 (0.122)	-0.53 (0.177)	-0.73 (0.228)	0.69
US4	4.16 (1.085)	0.220 (0.119)	-0.37 (0.113)	-0.65 (0.163)	-0.75 (0.190)	0.74
US5	3.31 (0.976)	0.277 (0.119)	-0.42 (0.114)	-0.44 (0.154)		0.51
US6	3.62 (0.935)	0.226 (0.115)	-0.40 (0.108)	-0.57 (0.146)	-0.64 (0.174)	0.66

US4 and US6 with $A_0 = \text{AVG}$, US3 with $A_0 = 0.49$.

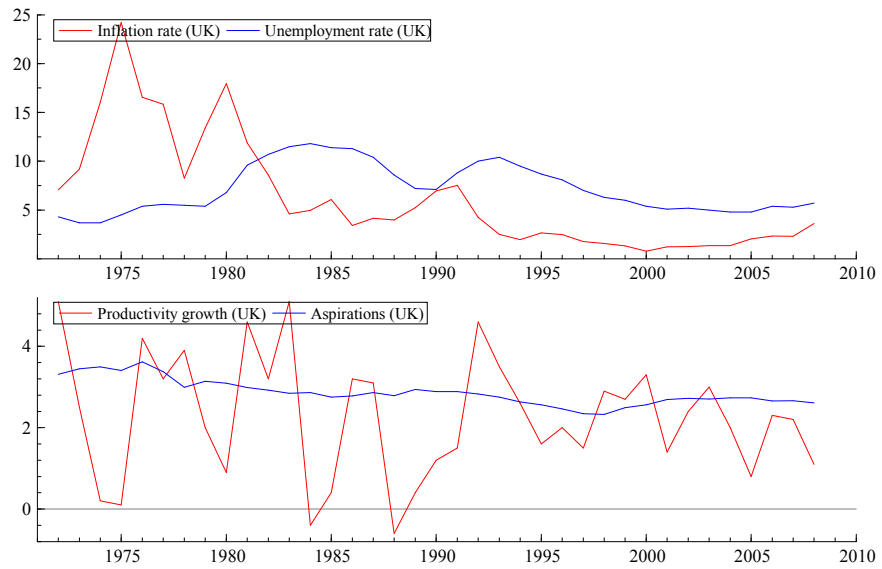
β_1 is the coefficient on $\Delta\pi_{t-1}$ and β_2 is the coefficient on $\Delta\pi_{t-2}$.



Top graph: Inflation and unemployment rates for the U.S.

Bottom graph: (labor) productivity growth and aspirations for the U.S.

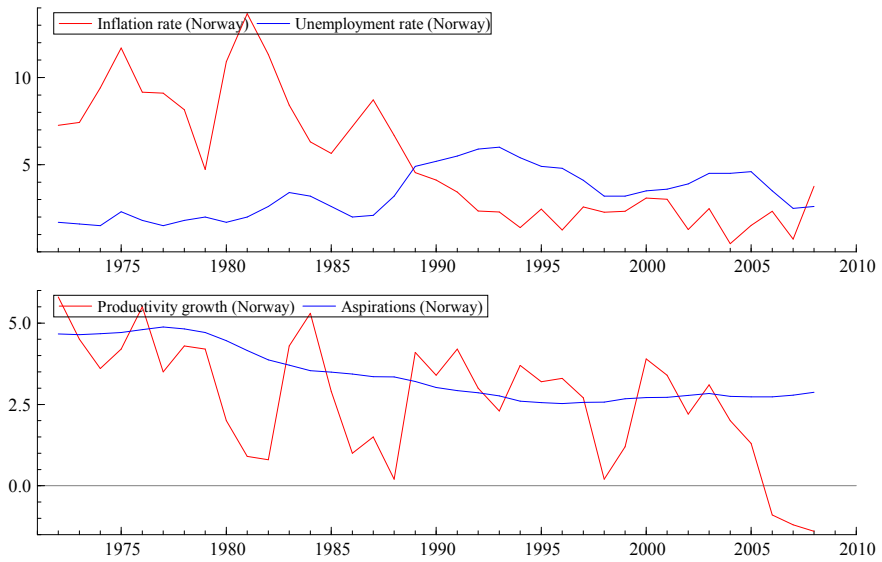
Source: OECD Stat.Extracts (<http://www.oecd.org>)



Top graph: Inflation and unemployment rates for the U.K.

Bottom graph: (labor) productivity growth and aspirations for the U.K.

Source: OECD Stat.Extracts (<http://www.oecd.org>)



Top graph: Inflation and unemployment rates for Norway
 Bottom graph: (labor) productivity growth and aspirations for Norway
 Source: OECD Stat.Extracts (<http://www.oecd.org>)